

# A left-right $SU(7)$ symmetric model with $\mathcal{D}$ -parity cosmic strings

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## Abstract

Cosmic strings with the property of  $\mathcal{D}$ -parity symmetry are studied in this paper. They are of a  $\mathbb{Z}_2$  type of strings that could appear in the spontaneous breaking of  $SU(7)$  and would present extraordinary properties in a background of ordinary and mirror neutrinos. Through the special embedding of the left-right symmetry in  $SU(7)$ , with a minimal content of Higgs fields, based on two singlets and two doublets, it is possible to assure the topological stability of this type of cosmic strings. In their presence we could have a neutral flavor changing interaction between ordinary and mirror neutrinos as well as the formation of superconducting currents in the form of zero modes of neutrino mirrors that would show interesting effects.

## 1 Introduction

The cosmological scenario generally accepted today is that the universe, in its cooling process, has suffered a sequence of phase transitions in which symmetries were spontaneously broken until arriving to the symmetry of nature as we presently observe:  $SU(3)_C \otimes U(1)_{e.m}$  [1]. In consequence, according to the Kibble mechanism [2] the formation of extended topological objects like cosmic strings could have arisen if the topology of the vacuum manifold of the symmetry is nontrivial. Topological defects are also real objects in low energy physics of the condensed matter. Some well-known examples are flux tubes in superconductors and vortices in superfluid helium-4 [3].

There are two forms of classifying cosmic strings: the first one uses the Wilson-line integral at infinite radius  $U(\theta) = P \exp \left[ \int_0^\theta \mathbf{A} \cdot d\mathbf{l} \right]$ , where  $P$  represents the path ordering of the exponential. This generates the condensate winding at spatial infinity  $\langle \phi(\theta) \rangle = U(\theta) \langle \phi(0) \rangle$ , where  $\langle \phi \rangle$  is the vacuum expectation value of the Higgs field producing the breaking  $G \xrightarrow{\longrightarrow} \phi H$ . This is the

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case for  $U(2\pi) = h \in H$ , being  $H$  the little group of the Higgs field  $\langle\phi(0)\rangle$ . Thus, the cosmic strings that can be formed in this breaking are specified by the possible values of  $U(2\pi)$  – the elements of  $H$ . The other form of classifying cosmic strings is to specify the topological class of a string, such that the vacuum manifold  $G/H$  has a nontrivial fundamental group, i.e., the elements of the first homotopy group  $\pi_1(G/H)$  are nontrivial. In general,  $m$ -dimensional defects in a  $d$ -dimensional medium are classified by the homotopy group  $\pi_n(G/H)$  where[4]  $n = d - m - 1$ , such that, when  $n = 0, 1, 2$  the objects formed are domain walls, cosmic strings and magnetic monopoles, respectively.

A cosmic strings model based in the product group  $SO(10) \otimes SO(10)' \subset SO(20)$  GUT with  $SO(10)$  being the symmetry of ordinary matter and  $SO(10)'$  describing the mirror matter was constructed by Schwarz [5]. This kind of objects have the extraordinary property of transforming an ordinary particle in a mirror particle when this particle gives a turn around the string. This type of cosmic strings are considered as an Alice string [6]. A model of mirror cosmic strings as possible sources of ultrahigh energy neutrinos was constructed by Berezinsky et al.[7]. Some models of left-right cosmic strings [8][9] as well as  $B - L$  cosmic strings also exists in the literature [10]. Although explicit supersymmetric models of cosmic strings have been built [11], explicit models of cosmic strings in  $SU(N > 5)$  GUT's with mirror matter have not been considered in the literature. Some of the difficulties of this class of models were to reproduce the well-known phenomenology of low energy. But it is also possible that this kind of objects have been formed in the TeV scale or in the electro-weak scale, with the possibility of having experimentally sizeable effects.

The connection between left-right symmetric models and cosmic strings is very appealing but finds a fundamental phenomenological difficulty: the Higgs sector that breaks the parity symmetry has a large number of unknown fundamental parameters and we have no direct connection with the cosmic strings scales.

Recently we have studied [14, 15] a new mirror left-right symmetric model. In this model we have shown that  $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$  can be broken to the standard model group with a Higgs sector containing only two doublets and two singlets. In this model parity is broken by the  $\mathcal{D}$ - parity mechanism and an  $SU(7)$  GUT model is proposed.

In the present paper we have constructed a cosmic strings model of the type  $\mathbb{Z}_2$ , and have called it a  $\mathcal{D}$ - parity cosmic strings, based in a  $SU(7)$  GUT with a especial embedding in order to incorporate the minimal left-right symmetry as a subgroup and include mirror matter. A careful election of the Higgs fields is necessary to get the topological stability of this cosmic strings until our days.

We have also the possibility of  $B - L$  cosmic strings in our model, but the presence of  $SU(2)_R$  would destabilize them [8]. This type of strings are produced when a factor  $U(1)_{B-L}$  (that contain a  $\mathbb{Z}_2$  discrete symmetry which can be left unbroken down to low energies) is broken by a Higgs scalar in a complex representation of  $G$ .

The  $P$ -parity spontaneously breaking will happen with the break of the left-right components in the low energy stage governed by the symmetry  $SU(3)_C \otimes$

$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$  [12][13][14].

Our paper is organized as follow: after making some general comments in the introduction, in the section 2 we analyze the breakdown of  $SU(7)$  and the consequent appearance in our model of  $\mathcal{D}-$  parity cosmic strings. In section 3 we present the question of magnetic monopoles in the phase transitions. The mechanism of generation of superconducting currents with neutrino mirrors as well as the flavor changing between ordinary and mirror neutrinos is approached in section 4. In section 5, final comments and conclusions are provided.

## 2 Breakdown of $SU(7)$ and $\mathcal{D}-$ parity cosmic strings

The spontaneous breaking of  $SU(N)$  gauge theories usually can be made through the fundamental representation  $\mathbf{N}$  or with multiplets corresponding to the direct product  $(\mathbf{N}^2 - \mathbf{1}) \otimes (\mathbf{N}^2 - \mathbf{1})$ . However, to find Higgs multiplets producing  $\mathbb{Z}_2$  cosmic strings in a semisimple gauge group  $G$  it is necessary to observe that the chiral fermions must be placed in a irreducible fundamental representation. Then it is necessary to look for the product  $\mathbf{N} \otimes \mathbf{N}$  for the symmetrical component of higher weight giving masses to the fermions[21]. This is the habitual procedure for  $G = SO(10), E_6, E_7, E_8$ . Nevertheless, in  $SU(N)$  grand unified gauge theories the chiral fermions are placed in combinations of representations in such a way that they eliminate the anomalies. For  $SU(7)$ , our election, free of anomalies, is  $\{\mathbf{7}\} \oplus \{\mathbf{21}^*\} \oplus \{\mathbf{35}\}$ .

An interesting class of cosmic strings arises from the following breaking chain of  $SU(7)$

$$\begin{aligned} SU(7) &\xrightarrow{S_M} SU(5) \otimes SU(2)_R \otimes \mathcal{Z}_2 \xrightarrow{S_D} \\ &SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \otimes \mathcal{Z}_2 \xrightarrow{\chi_R} \\ &SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes \mathcal{Z}_2 \xrightarrow{\chi_L} SU(3)_C \otimes U(1)_{e.m} \otimes \mathcal{Z}_2. \end{aligned} \quad (1)$$

The matter content is included in the decomposition of the representations of the symmetry breaking Higgs fields and the fundamental fermions multiplet under the  $SU(5) \otimes SU(2)_R \otimes U(1)_X$  maximal subgroup<sup>1</sup> of  $SU(7)$ :

$$\{\mathbf{63}\} = \{\mathbf{7}\} \oplus \{\mathbf{21}^*\} \oplus \{\mathbf{35}\}, \quad (2)$$

$$\{\mathbf{21}^*\} = [\mathbf{1}, \mathbf{1}, \mathbf{10}] \oplus [\mathbf{5}^*, \mathbf{2}, \mathbf{3}] \oplus [\mathbf{10}^*, \mathbf{1}, -\mathbf{4}], \quad (3)$$

$$\{\mathbf{48}\} = [\mathbf{24}, \mathbf{1}, \mathbf{0}] \oplus \dots \quad (4)$$

where we have indicated only those pieces that acquire vacuum expectation values for  $\{\mathbf{21}^*\}$  and  $\{\mathbf{48}\}$ .

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<sup>1</sup>Our notation is:  $\{\quad\}$  for  $SU(7)$ ,  $[\quad]$  for the components under  $SU(5) \otimes SU(2)_R \otimes U(1)_X$  and  $(\quad)$  for  $SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$  decompositions. It should be noticed that  $\{\mathbf{63}\}$  it is not an irreducible representation of  $SU(7)$ .

Our election for the Higgs multiplets is  $S_M \sim \{\mathbf{21}^*\} \oplus \{\mathbf{1}\} \supset [\mathbf{1}, \mathbf{1}, 10] \oplus [\mathbf{1}, \mathbf{1}, 0]$ , i.e.,  $S_M$  is some linear combination of Higgs fields in the  $\{\mathbf{21}^*\}$  and  $\{\mathbf{1}\}$  representations along with their coupling strengths. The first component  $S_M(\mathbf{21}) \sim \{\mathbf{21}^*\} \supset [\mathbf{1}, \mathbf{1}, 10] \sim (\mathbf{1}, \mathbf{1}, \mathbf{1}, 0)$  it should be responsible for producing cosmic strings. We clarify our election of the Higgs field breaking  $SU(7)$ . In reality, from the product of the fundamental representations  $\{\mathbf{7}\} \otimes \{\mathbf{7}\} = \{\mathbf{21}\}_A \oplus \{\mathbf{28}\}_S$  we can see that  $\{\mathbf{28}\} = [\mathbf{15}, \mathbf{1}, 4] \oplus [\mathbf{5}, \mathbf{2}, -3] \oplus [\mathbf{1}, \mathbf{3}, -10]$  doesn't contain any component that can break  $SU(7)$  leaving invariant  $SU(5) \otimes SU(2)_R$  in the next stage, as it is our desire. A different situation happens for  $\{\mathbf{21}\}_A$  that contain the appropriate piece  $[\mathbf{1}, \mathbf{1}, -10]$  in order to construct cosmic strings  $\mathcal{Z}_2$  with the surprising property of changing flavors of ordinary and mirrors neutrinos. However, as it was observed in reference [25], in unified theories it is also possible to generate fermion masses using antisymmetric representations. Although in our model neutrinos don't receive masses at the tree level from  $\{\mathbf{21}\}_A$  at the GUT scale, it is vital to generate radiative neutrino masses [15]. For this reason, we have done the election of antisymmetric components of  $\mathbf{N} \otimes \mathbf{N}$  that would also produce different types of cosmic strings  $\mathcal{Z}_2$ .

The second term  $S_M(\mathbf{1}) \sim \{\mathbf{1}\} \supset [\mathbf{1}, \mathbf{1}, 0]$  could generate superheavy mass to some neutrinos as well as driving the inflation scenario, as we will see below. The following decompositions are necessary

$$\begin{aligned} \{\mathbf{35}\} &= [\mathbf{10}^*, \mathbf{1}, 6] \oplus [\mathbf{5}, \mathbf{1}, -8] \oplus [\mathbf{10}, \mathbf{2}, -1], \\ \{\mathbf{48}\} &= [\mathbf{1}, \mathbf{1}, 0] \oplus [\mathbf{1}, \mathbf{3}, 0] \oplus [\mathbf{24}, \mathbf{1}, 0] \oplus [\mathbf{5}, \mathbf{2}, 7] \oplus [\mathbf{5}^*, \mathbf{2}, -7], \\ \{\mathbf{224}\} &= [\mathbf{40}, \mathbf{1}, 4] \oplus [\mathbf{24}, \mathbf{1}, -10] \oplus [\mathbf{45}, \mathbf{2}, -3] \oplus [\mathbf{10}^*, \mathbf{2}, 11] \oplus [\mathbf{5}, \mathbf{2}, -3] \\ &\quad \oplus [\mathbf{10}, \mathbf{1}, 4] \oplus [\mathbf{10}, \mathbf{3}, 4], \end{aligned} \tag{5}$$

The next important fields are  $S_D \sim \{\mathbf{48}\} \supset [\mathbf{24}, \mathbf{1}, 0] \supset (\mathbf{1}, \mathbf{1}, \mathbf{1}, 0)$ ,  $\chi_R \sim \{\mathbf{35}\} \supset [\mathbf{10}, \mathbf{2}, -1] \supset (\mathbf{1}, \mathbf{1}, \mathbf{2}, 1)$  and also  $\chi_L \sim \{\mathbf{224}\} \supset [\mathbf{10}, \mathbf{1}, -4] \supset (\mathbf{1}, \mathbf{2}, \mathbf{1}, 1)$  which are invariant under  $2\pi$  rotations because they are not spinorial representations.

The fermions content is deployed [15] in the representations  $\{\mathbf{1}\}, \{\mathbf{7}\}, \{\mathbf{21}\}$  and  $\{\mathbf{35}\}$  with the anomaly free combinations  $\{\mathbf{1}\} \oplus \{\mathbf{7}\} \oplus \{\mathbf{21}^*\} \oplus \{\mathbf{35}\}$ . These selected Higgs multiplets can give masses to all the fermions as it can be directly verified from the tensorial products [16]:

$$\begin{aligned} \{\mathbf{7}^*\} \otimes \{\mathbf{7}\} &= \{\mathbf{1}\} \oplus \{\mathbf{48}\}, \\ \{\mathbf{7}\} \otimes \{\mathbf{7}\} &= \{\mathbf{21}\}_A \oplus \{\mathbf{28}\}_S, \\ \{\mathbf{7}\} \otimes \{\mathbf{35}\} &= \{\mathbf{35}^*\} \oplus \{\mathbf{210}\}, \\ \{\mathbf{7}^*\} \otimes \{\mathbf{35}\} &= \{\mathbf{224}\} \oplus \{\mathbf{21}\}, \\ \{\mathbf{21}\} \otimes \{\mathbf{35}\} &= \{\mathbf{224}\} \oplus \{\mathbf{21}^*\} \oplus \dots, \\ \{\mathbf{21}^*\} \otimes \{\mathbf{21}\} &= \{\mathbf{1}\} \oplus \{\mathbf{48}\} \oplus \dots, \\ \{\mathbf{21}\} \otimes \{\mathbf{21}\} &= ((\{\mathbf{196}\} \oplus \{\mathbf{35}\})_S \oplus \{\mathbf{210}\}_A), \\ \{\mathbf{35}^*\} \otimes \{\mathbf{35}\} &= \{\mathbf{1}\} \oplus \{\mathbf{48}\} \oplus \dots \end{aligned} \tag{6}$$

The remaining particles that didn't obtain their masses at the tree level, will obtain their masses from radioactive corrections.

The  $\mathcal{Z}_2$  symmetry that appears in (1) is the discrete remnant of a broken  $U(1)_X$ , which can be identified as  $\mathcal{D}$ - parity symmetry [13] as is evident from the next stage of symmetry breaking.

Now we pass to describe the breaking chain (1). If one begins with a simply connected gauge group  $G$ , strings will not arise in a phase transition in which  $G$  is spontaneously broken. This is the case for  $SU(7)$  as in any GUT based in  $SU(N)$  or  $Spin(N)$ ; strings will not arise at the first stage of symmetry breaking [17]. Then, the breakdown of  $SU(7)$  to its maximal sub-group  $SU(5) \otimes SU(2) \otimes U(1)_X$  will not produce strings. The previous  $SU(2)$  factor is assumed to be the right sector, i.e. we assume  $SU(2)_R$ . This is possible because the generators of  $SU(2)_R$  are included in  $SO(14)$  and  $SU(7)$  is naturally embedded in  $SO(14)$ .

However,  $SU(5) \otimes SU(2)_R$  is connected and by virtue of a well-known property of the homotopy groups[4]  $\pi_{i-1}SU(n) = \pi_{i+1}SU(n), i \leq 2m \leq n$ . So we have  $\pi_0(SU(5)) = 0$  and  $\pi_0(SU(2)) = 0$ , and then

$$\pi_1\left(\frac{SU(7)}{SU(5) \otimes SU(2)_R \otimes \mathcal{Z}_2}\right) = \pi_0(SU(5) \otimes SU(2)_R \otimes \mathcal{Z}_2) = \mathcal{Z}_2. \quad (7)$$

The kind cosmic strings formed in this stage of breaking symmetry has energy per unit length  $\sim \langle S_M(\mathbf{21}) \rangle^2$  and could be called *D-parity cosmic strings* for arguments that we will be giving soon. According to the products given in (6), the following relevant couplings conserving the  $U(1)_X$  charge are possible:

$$\begin{aligned} \{\mathbf{21}^*\} \otimes \{\mathbf{1}\} \otimes \{\mathbf{21}_H\} &\supset \overline{\nu_{eR}} N_{EL} \widetilde{S_M}(\mathbf{21}), \\ \{\mathbf{1}\} \otimes \{\mathbf{1}\} \otimes \{\mathbf{1}_H\} &\sim \overline{N_{EL}^C} N_{EL} S_M(\mathbf{1}), \\ \{\mathbf{7}^*\} \otimes \{\mathbf{7}\} \otimes \{\mathbf{1}\}_H &\supset \overline{\nu_{\mu R}^C} \nu_{\mu R} S_M(\mathbf{1}), \overline{N_{ML}^C} N_{ML} S_M(\mathbf{1}), \\ \{\mathbf{7}\} \otimes \{\mathbf{7}\} \otimes \{\mathbf{21}_H^*\} &\supset \overline{\nu_{\mu R}} N_{ML} S_M(\mathbf{21}) \end{aligned} \quad (8)$$

Similar couplings arise for the multiplets in  $\mathbf{64}^* = \{\mathbf{1}\} \oplus \{\mathbf{7}^*\} \oplus \{\mathbf{21}\} \oplus \{\mathbf{35}^*\}$ , where we can accommodate the lepton  $\tau$  family, a new fourth family of "ordinary" leptons  $l_{\theta L}^C = \binom{\nu_{\theta L}}{\theta_L}^C \subset \{\mathbf{7}^*\}$ , its quarks  $q_L^C = \binom{o_L}{a_L}^C \subset \{\mathbf{35}\}^*$  and its respective mirror partners [15].

In the following stage for the breaking chain (1) it is possible that  $B - L$  cosmic strings could be formed since

$$\pi_1\left(\frac{SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}}{SU(3)_C \otimes SU(2)_L \otimes U(1)_Y}\right) = \mathcal{Z}_2. \quad (9)$$

Thus, as  $\mathcal{Z}_2$  it is not already contained in a continuous connected invariance group  $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$  of the vacuum,  $B - L$  cosmic strings of energy per unit length  $\sim \langle \chi_R \rangle^2$  can appear in this stage. However, it was showed in [8] that this  $\mathcal{Z}_2$  as expected from the breakdown of  $U(1)_{B-L}$  group, by itself does not persist due to the presence of the  $SU(2)_R$ . Thus, the  $B - L$  cosmic strings appearing in this stage will be unstable and decaying quickly. In the phenomenological context, it is also important to notice that  $\mathcal{P}$ - parity is spontaneously

broken along with the group  $SU(2)_R$ . Some low energy phenomenologic aspects of  $SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$  with mirror matter were studied in [15][18].

### 3 Monopoles in the phase transitions

In this section we look for the formation of other topological defects, such as monopoles, in the breaking chain (1). As it was recognized in the literature, the symmetry of matter parity  $\mathcal{Z}_2$  is important in order to preserve large values for the proton lifetime, and also because it guarantees the topological stability of cosmic strings. Let us use the Kibble mechanism [2] based in homotopy theory to find monopoles. Thus  $\pi_2\left(\frac{SU(7)}{SU(5) \otimes SU(2)_R \otimes \mathcal{Z}_2}\right) = \pi_1(SU(5) \otimes SU(2)_R \otimes \mathcal{Z}_2) = \mathcal{I}$  is trivial. According to the Kibble mechanism [2] topological monopoles are not formed during the first phase transition in (1). Let us also notice the relations

$$\begin{aligned} & \pi_2\left(\frac{SU(7)}{SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \otimes \mathcal{Z}_2}\right) \\ &= \pi_1(SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \otimes \mathcal{Z}_2) = \mathcal{Z}, \end{aligned} \quad (10)$$

$$\begin{aligned} & \pi_2\left(\frac{SU(7)}{SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes \mathcal{Z}_2}\right) \\ &= \pi_1(SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes \mathcal{Z}_2) = \mathcal{Z}, \end{aligned} \quad (11)$$

$$\pi_2\left(\frac{SU(7)}{SU(3)_C \otimes U(1)_{e.m} \otimes \mathcal{Z}_2}\right) = \pi_1(SU(3)_C \otimes U(1)_{e.m} \otimes \mathcal{Z}_2) = \mathcal{Z}. \quad (12)$$

Thus, starting from the second phase transition in the breaking chain (1), topological magnetic monopoles were formed which will be topologically stable until low energies. These objects, if they are present until our days, would be dangerous for the universe because they would dominate the energy density quickly. Consequently, it is necessary to appeal to inflation to dilute them. This is possible if the singlet  $SU(7)$ ,  $\{\mathbf{1}\}$  is assumed to be the responsible to generate the inflation scenario. We assume a coupling between  $S_D \sim \{\mathbf{48}\}$  producing monopoles, and  $\{\mathbf{1}\}$  driving the inflation by means of a hybrid inflation potential, for example as given in [19]. This mechanism, together with the monopole-antimonopole pair nucleation could dilute necklaces cosmic strings [20] possibly formed in this phase transition. To avoid that cosmic strings are thrown away or dissociated as consequence of the inflation, we suppose some discrete symmetry to avoid a coupling between the  $\{\mathbf{1}_H\} \sim S_M(\mathbf{1})$  and the  $\{\mathbf{21}_H^*\} \sim S_M(\mathbf{21})$ .

### 4 Neutrino effects in $\mathcal{D}-$ parity cosmic strings

We begin with the first phase transition  $SU(7) \xrightarrow{\widetilde{S_M}} SU(5) \otimes SU(2)_R \otimes \mathcal{Z}_2$ . The type of cosmic strings taking place in this phase transition is  $\mathcal{Z}_2$  [21]. The only

supermassive fermions in this stage are  $N_{EL}$ ;  $\nu_{\tau R}$  and it's mirror partner  $N_{\Upsilon L}$  and  $\nu_{\mu R}$  with its mirror partner  $N_{ML}$ . They obtain Majorana masses of order  $10^{16} GeV$  through the component  $\{\mathbf{1}_H\} \sim S_M(\mathbf{1})$ .

A mixing of the type  $\overline{\nu_{eR}} N_{EL} \widehat{S_M}(\mathbf{21}) \subset \{\mathbf{21}^*\} \otimes \{\mathbf{1}\} \otimes \{\mathbf{21}_H\}$  has interesting effects. The cosmic strings solutions are given by the classical configurations  $S_M^{clas}(\mathbf{21}) = f(r) e^{i\theta} S_M^{(0)}(\infty)$  and  $A_\theta^{clas} = \frac{2a(r)}{gr} \delta_\theta^\mu$ ; where we are assuming the winding number  $n = 1$  and the vacuum expectation value is  $\langle S_M^{(0)}(\infty) \rangle = v_M/\sqrt{2}$  [1]. Thus, in this case a supermassive mirror electron neutrino  $N_{EL}$  coming closer from the space infinity to the anti-cosmic string, where  $a(r)$ ,  $f(r) \rightarrow 1$ , after giving a complete turn of  $2\pi$  around of the anti-cosmic string becomes  $\nu_{eR}$ . An analogous situation will be present between  $\nu_{\tau R}$  and their mirror partner  $N_{\Upsilon L}$ .

The formation of zero modes is also possible if we add the quantum fluctuations to the classical configurations of the Higgs and gauge fields of the string:  $S_M(\mathbf{21}) = S_M^{clas}(\mathbf{21}) + \widehat{S_M}(\mathbf{21})$ ,  $A_\mu = A_\mu^{clas} + \widehat{A}_\mu$  in an analogous way as to the capture of an electron by a nucleus with the emission of a photon. In this sense, it is expected the capture of  $N_{EL}$  by the anti-string and the subsequent formation of zero mode of  $\nu_{eR}$  with the emission of the scalar Higgs or the vectorial boson  $A_\mu$  that form the anti-string. The inverse process is also possible. If the necessary kinematic considerations are allowed, we can have the capture of an  $\nu_{eR}$  and the formation of neutral currents with the mirror electron neutrino  $N_{EL}$  and the emission of bosons from the string. One should not forget that at this stage these currents are massless because in the string we have  $a(r)$ ,  $f(r) \rightarrow 0$  as  $r \rightarrow 0$ .

A similar situation will take place through the coupling  $\{\mathbf{7}\} \otimes \{\mathbf{7}\} \otimes \{\mathbf{21}_H^*\} \supset \overline{\nu_{\mu R}} N_{ML} S_M(\mathbf{21})$  where a mirror muon neutrino  $N_{ML}$  giving a complete turn of  $2\pi$  around of the cosmic string becomes a  $\nu_{\mu R}$  with the possibility of forming massless zero modes by means of the same mechanism as described before. Thus, it is possible to generate superconducting currents with mirror neutrinos. Similar ideas were placed by one of the authors in a model of superconducting cosmic strings  $SO(10)$  in order to explain UHECR [22]. Processes of flavor changing neutral currents in cosmic strings and domain walls were also analyzed in [23]. The extraordinary consequence of our model is that in the presence of this type of cosmic string, flavor changes of neutrinos would take place through  $N_{EL} \leftrightarrow \nu_{eR}$ ,  $N_{\Upsilon L} \leftrightarrow \nu_{\tau R}$ ,  $N_{ML} \leftrightarrow \nu_{\mu R}$ ,  $N_{\Theta L} \leftrightarrow \nu_{\theta R}$ . This is the reason why we call these strings  $\mathcal{D}$ - parity cosmic strings. It is also possible that this type of topological defects could hide mirror neutrinos until today in the form of massless zero modes.

## 5 Comments and conclusions

We have built a model of  $\mathcal{Z}_2$  cosmic strings which we have called  $\mathcal{D}$ - parity cosmic strings in virtue to their extraordinary property of changing flavor between ordinary neutrinos and mirrors neutrinos, in the GUT scale, when one of

them gives a complete turn around the string. Our type of string is not an Alice string in which a particle is transformed in its anti-particle. This extraordinary property of this type string is a consequence of the mixing between ordinary neutrinos and their mirror partners through the field of a Higgs particle in the string and of the magnetic flow inside the string that makes a rotation of the fermion field approaching to it from very far.

A more realistic model of  $\mathcal{D}$ -parity cosmic strings could arise from a breaking chain of the type

$$\begin{aligned} G \rightarrow \tilde{H} \otimes \mathcal{Z}_2 \rightarrow H \otimes \mathcal{D} \otimes \mathcal{Z}_2 \rightarrow SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \otimes \mathcal{Z}_2 \\ \rightarrow SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes \mathcal{Z}_2 \rightarrow SU(3)_C \otimes U(1)_{e.m} \otimes \mathcal{Z}_2, \end{aligned} \quad (13)$$

where  $G = SO(14)$ ,  $\tilde{H} = SU(7)$  and  $H = SU(5) \otimes SU(2)_R$ . In reality, the first phase transition it can be produced for an Higgs in<sup>2</sup>  $\mathbf{1716}_S \subset \mathbf{64} \otimes \mathbf{64}$  through of it's singlet component that leaves invariant the factor  $SU(7)$ . The second phase transition could be produced for  $\mathbf{91} \supset \{\mathbf{1}\} \supset [\mathbf{1}, \mathbf{1}, 0]$  which is even under  $\mathcal{Z}_2$  and the third phase transition by other  $\mathbf{91} \supset \{\mathbf{21}\} \supset [\mathbf{1}, \mathbf{1}, -10]$  which is odd under  $\mathcal{D}$ -parity but is even under  $\mathcal{Z}_2$ . Thus, the Left-Right hierarchy is induced of natural way in our breaking chains (13). In the presence of mirror matter this type of cosmic strings could have important effects [24].

Superheavy neutrinos mirror could also be the source of UHECR through the mechanism of generation of superconducting currents described here. In this context, if they were captured at the beginning of the friction period, an estimative of the vortons density indicates that it would be more relevant for UHECR in this period than in the scaling regime [22].

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<sup>2</sup>Here  $\mathbf{R}$ -representations correspond to  $SO(14)$ .

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